The Supply Security of Hydrogen as Transport Fuel

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The supply security of hydrogen as transport fuel

by
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Abstract

The impact that hydrogen and fuel cell technology can have on the security of European transport fuel supply is addressed in this paper. This impact depends primarily on the primary energy commodities that serve as feedstock in the production of hydrogen. Natural gas as feedstock does not provide any improvement of security of supply. Coal with carbon capturing and sequestration provides in some respects a more secure supply of energy as will nuclear power. Renewable electricity and biomass based hydrogen does, however, offer a more secure supply in the sense that they are domestic and renewable.

Acknowledgements:

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Academic disciplines involved:

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Keywords:

Hydrogen feedstock, renewable and non-renewable resources

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Introduction

Supply Security and Risks of Energy Supply Disruption

"Security of energy supply" has a diversity of meanings. It can refer to long or short term energy supply, to supply problems related to geological, geopolitical or market power factors, to vulnerabilities of the global fuel throughput and national power grid balance, and to several other aspects. In a recent report from the International Energy Agency (IEA) (2007a) the distinction is made between a price component and a physical availability component of supply security. International Energy Agency (IEA) (2007b) also stresses that supply security is a question of the global demand. In casu the surge in global energy demand from China and India and other emerging economies.

From a strictly economic point of view supply constraints boil down to higher prices – in particular, when it is viewed relative to demand. Therefore, supply security and price stability are two sides of the same coin. From a geopolitical point of view, however, the threat of supply constraints undermines political independence and this adds a dimension to the problem which is of equally high societal concern. Furthermore, the reliability of a continuous flow or throughput of energy is important for risk assessment of investment and for the cost of infrastructure and security measures.

In the following we examine three supply security aspects of hydrogen feedstocks related to the international energy markets

Price dependence

Risk of market power and the use of it for political purposes

Global scarcity

Finally we examine the vulnerability of the European economies to oil and gas price increases.

Strategies to Secure Energy Supply

The responses to risks associated with the supply of energy to the European economies are as diverse as the sources. Demand side regulation reduces the dependence of the energy supply. Diversification of energy sources and enhancing their substitutability make the market less vulnerable to disruptions in supply from individual sources. Investment in domestic energy resources build up an energy capacity that can not be controlled by foreign powers. Distributed rather than centralised networks offers insurance benefits supporting the resilience of the system balances (fuel throughput and voltage).

Such achievements in the security of energy supply come at a cost, but in some cases they can entail side benefits neutralising these. Demand side regulation can constrain some economic activities, but can also help directing focus at energy uses with little or no purpose. Diversification policies could lead to use of energy technologies that are not cost competitive, but the very use of them also entails learning economies that make them competitive in the long run. Domestic energy resources can be more expensive than imported energy commodities, but the trade balance effects can be important in many countries. Distributed energy production and conversion forgo much of the scale economies in the sector, but enhances the opportunities to exploit economies of scope: The combined production of various forms of energy commodities, notably power and heat.

Can hydrogen contribute to supply security?

The societal priorities pursued by the energy policy of virtually every country include security of energy supply, low cost of energy - and thus good options for economically beneficial activities using energy consuming processes – and low environmental pressure caused by the production and use of energy.

Considering the fundamental role of energy in achieving high rates of productivity growth in the past, the achievement of simultaneous progress in all three dimensions represents huge macroeconomic challenges.

There are trade-offs between all three priorities but win-win options and even win-win-win options are also available.

The topic of this paper is the role that can be played by automotive use of hydrogen and fuel cell technology in these trade-offs. Will the technology make it easier or more difficult to meet the macroeconomic challenges?

The Convertibility of Hydrogen

The responses to the supply security challenge include diversification of energy supply sources and the increasing the market share of the sources that are most reliable.

In the power and heat sector, the formerly strong oil dependency have been relieved by a range of other primary energy supply solutions such as natural gas, nuclear, coal, biomass, and wind. Diversification of fuel supply for the transport sector, however, has turned out to be much more difficult, and it remains almost completely fuelled by oil based fuels. Even when alternatives are potentially cost competitive they seem to be unable to be successful unless they are introduced in coordination with a range of other innovations along the fuel chain and the vehicle supply. This situation is often referred to as a “technological lock-in”.

The H_2&FC technologies offer a potential solution to this because of its convertibility to and from any other energy carrier. The problem is that conversion costs energy as well as non-energy resources and that the establishment of conversion capacities requires thorough changes in infrastructure and technology throughout the WtW chain.

Thus the question of the primary energy basis for hydrogen is unavoidable for the planning efforts related to implementation of hydrogen and fuel cell technologies in automotive use. Diversification is not only a matter of the fuel. More important is the primary energy serving as feedstock in the production of fuels.

Alternative hydrogen feedstocks

The question is inspired by the experimental use of hydrogen for transport in a range of demonstration projects. In the Zero Region project hydrogen is supplied to and used from filling stations in Frankfurt a.M., Germany and Mantova, Italy. The production of hydrogen represents the two production technologies that are commercially viable in production of hydrogen for industrial use at the present: Electrolysis and natural gas reforming and thus the two primary energy feedstocks for hydrogen: Electricity and natural gas.

Much of the power added to the European power grids in the recent past has been based on natural gas and coal, but it is unlikely that it will be advantageous in any respect to use fossil fuels for power generation and then subsequently use the electricity for the production of hydrogen. The combined conversion loss from the two processes will almost certainly exceed that of direct production of hydrogen from fossil fuels.

Thus, we focus on hydrogen from electrolysis based on non-fossil power versus hydrogen produced from natural gas.

Fossil Energy based Hydrogen

Natural gas and coal price linkage to the oil price

The price of natural gas is closely linked to the price of oil. Contracts about natural gas delivered in the future are typically indexed to the spot market oil price 6-12 months before delivery. The result is shown in the figure below.

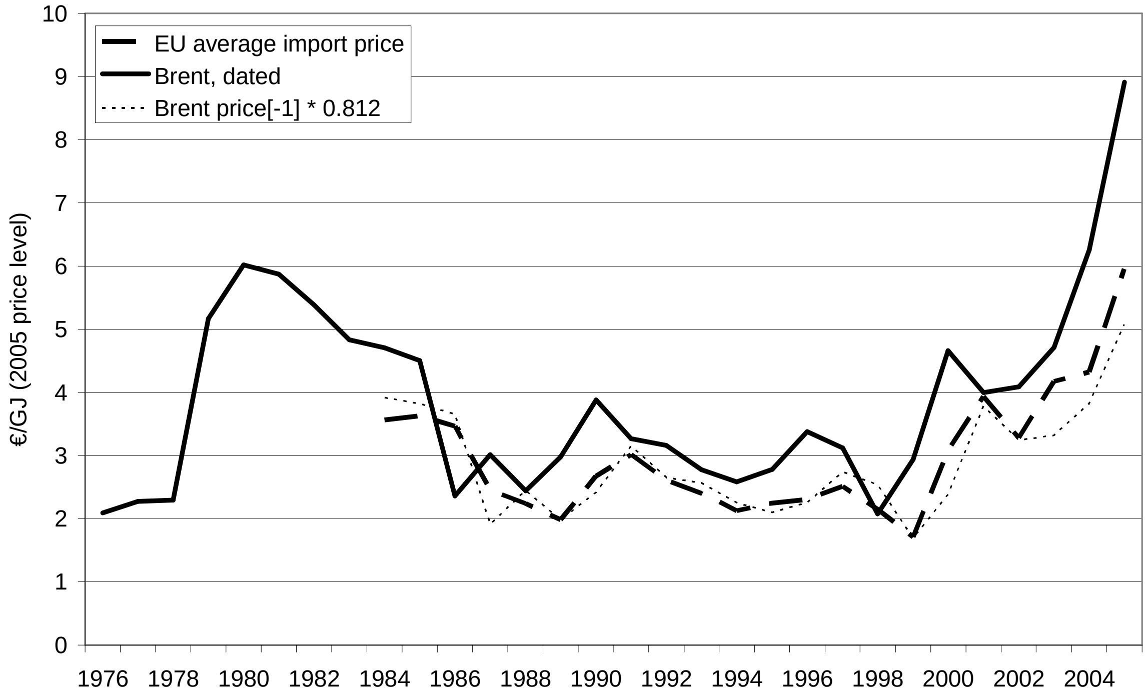

Figure 1. Natural Gas and Oil Prices 1976-2005.

Source: See Hansen (2007).

The figure shows that on the international natural gas market the price measured in €/GJ follows the price of oil in the preceding year quite closely. A good estimate of the natural gas price in a given year is simply 81.2% of the oil price in the preceding year as indicated by the estimated natural gas price curve. Note the prices here are deflated to the purchasing power of € in 2005. If we use current prices natural gas can be estimated as 84.2% of the oil price the preceding year.

There have been several European attempts to develop a natural gas market that has a price formation which is independent from the oil price. They seem to have been fruitless so far and the most important foreign supplier for Europe, Russia, has announced that its policy is to continue the oil price indexing practice and furthermore to follow the market price on oil as it results from the OPEC cartel agreements.

The fundamental economic reason for the close link between oil and natural gas is that they are very close substitutes for heating and electricity purposes. They will become even closer substitutes as compressed natural gas and natural gas based hydrogen gain market shares as transport fuels.

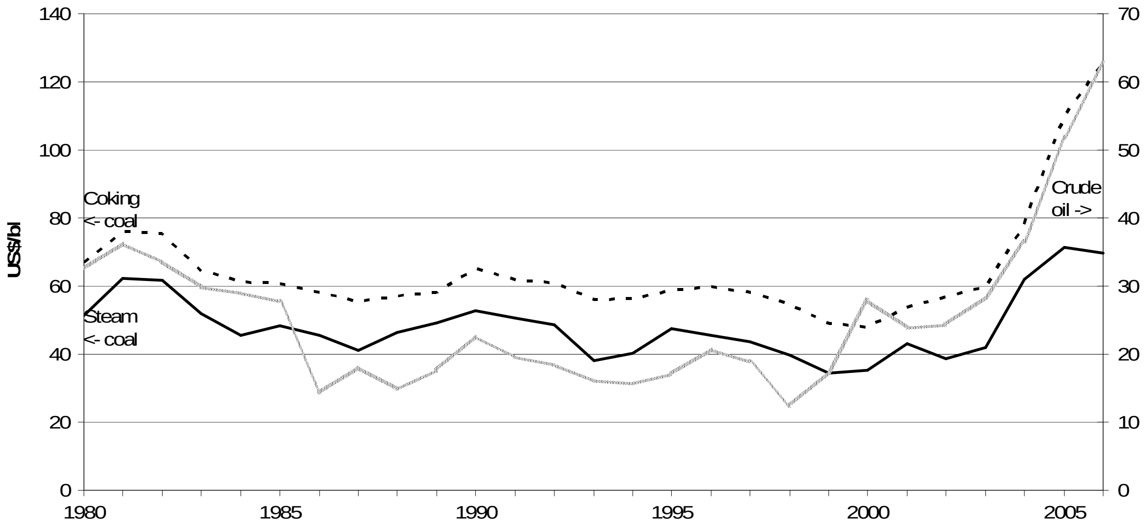

Figure 2. European Coal and Oil Prices 1980-2006.

Source: International Energy Agency (IEA): Energy prices and taxes. Database. http://www.oecd.org, 12.11.07.

The coal prices follow the oil price very closely too. Statistical analysis of the series showed in figure 2 revealed very significant elasticities of 0.74 for steam coal and 1.12 for coking coal prices to the average IEA crude oil import price.

Coal is a substitute for oil in many respects and is very energy consuming in transport. To the extent that coal is substituted for oil as feedstock in fuel production, we must expect this close relation to become even stronger. Additionally, a value added chain analysis by Gerling, Rempel et al. (2006) showed that about half the cost of coal in Europe in 2005 was transport costs that vary closely with the price of oil.

Summarizing, the price data don't support the idea that it should be possible to escape the oil price by substituting oil by other fossil fuels as feedstock in transport fuel production. On the contrary, the more such a substitution takes place, the closer the prices of the alternative will tend to change in parallel to the oil price.

Market Power and Geopolitical Risks

The geographical concentration of oil and gas resources is probably the main source of concern about supply security. The remaining oil reserves are located in a very limited range of countries, which gives opportunities for abuse of market power not only for economic reasons but also by the governments controlling it for foreign policy purposes. Market power is when the individual supplier or a group of suppliers can affect the level of supply to the market. If a reduction of supply from one producer is compensated by increased supply from other producers that producer does not posses market power.

The figure below shows the 9 countries that possess 70% of the remaining proven oil reserves in the world.

World Proven Oil Reserves 2005

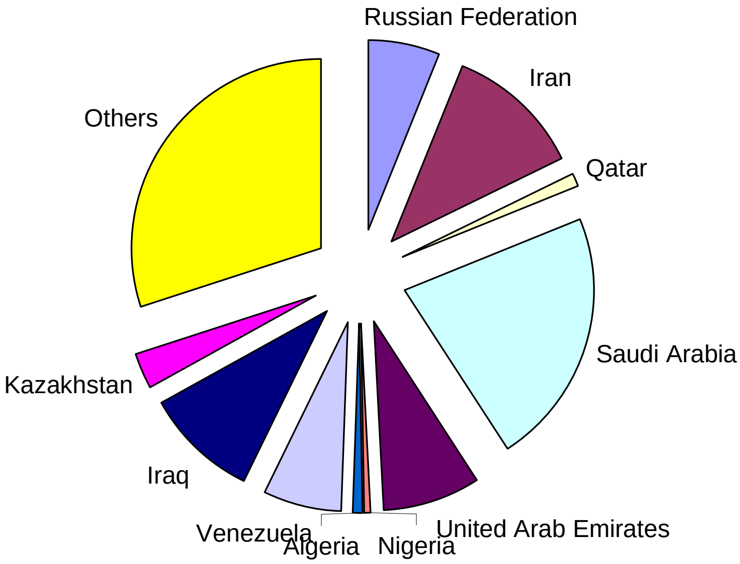

Figure 3. World Proven Oil Reserves 2005.

Data source: BP statistical review database 2006.

The possibility of such few suppliers to dominate prices and conditions through collusion is well known and has been used by the OPEC cartel since 1973 with the exception of the 1990s. With supply still more concentrated on fewer countries it becomes still more likely that the cartel discipline can be maintained and strengthened.

Replacing oil based transport fuels by natural gas based fossil fuels is one of the obvious solutions to the problem that has been pursued by Europe, but also elsewhere around the world, in the recent years. Natural gas is also characterised by emitting fewer pollutants by combustion than is known from petrol and diesel.

Natural gas is reserves are, however, not evenly distributed across the planet. The figure below shows the share of world proven gas reserves located in the nine oil countries.

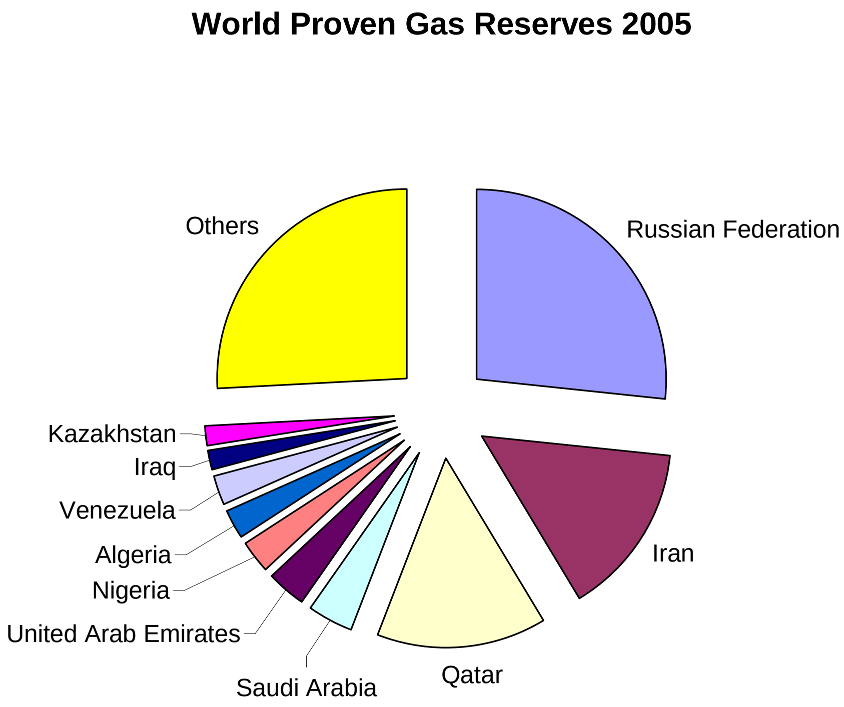

Figure 4. World Proven Natural Gas Reserves, 2005.
Data source: BP statistical review database 2006.

The major natural gas suppliers are also to a high degree identical with the major oil suppliers. The increasingly important natural gas supplier, Russia, has announced that its policy is to continue the oil price indexing practice and furthermore to follow the market price on oil as it results from the OPEC cartel agreements. The figures below show the share of world oil and gas reserves in the countries that are relevant to European natural gas supply (i.e., excluding North and Latin America and the Pacific).

The countries with more than 1.5% of the world proven natural gas reserves that are close to Europe possess 75% of the world proven reserves. The same countries control 70% of the world proven oil reserves.

Substituting natural gas for oil as primary energy source for transport provides an option to switch to an alternative as oil supply constraints emerge. But since the suppliers are largely the same and equally few, it is hard to expect a future of the natural gas market without collusion. The gas exporting countries have already formed the "Gas Exporting Countries Forum" and it is widely debated whether to develop it to a "Gas-OPEC".

The concerns related to political use of the market power at the oil market dates back to the notion that Middle East conflict was either a cause or an excuse for the first oil crisis in 1973-74 or both. Recent developments in Georgia and Ukraine – without claiming any deeper similarities – have convinced many Europeans that the gas market also has its power structures.

The oil price is particularly in a tight market affected by temporary supply disruptions at source due to, e.g., social conflict in Venezuela and Nigeria and climatic events. There is no reason to rule out similar events disrupting the natural gas supply.

Thus, the gains in supply security from substituting oil as the basis for transport fuels by natural gas are certainly positive, but they should not be exaggerated.

Substituting transport fuel feedstock from oil to coal would, however, base European transport on a much more abundant primary energy source which would also be much more dispersed.

Table 1. Proven Coal Reserves at End-2002 (Mt)

Table 5.2: **Proven Coal Reserves at End-2002** (Mt)

	Hard Coal	Brown Coal	Total
OECD Europe	22 420	17 041	39 461
OECD North America	218 818	35 614	254 432
OECD Pacific	39 677	38 033	77 710
OECD	**280 915**	**90 688**	**371 603**
Transition economies	**208 762**	**38 872**	**247 634**
of which Russia	*146 560*	*10 450*	*157 010*
China	95 900	18 600	114 500
East Asia	3 053	4 330	7 383
South Asia	90 146	5 350	95 496
of which India	*90 085*	*2 360*	*92 445*
Latin America	19 769	124	19 893
of which Brazil	*10 113*	–	*10 113*
Africa	50 333	3	50 336
Middle East	419	–	419
World	**749 297**	**157 967**	**907 264**

Source: World Energy Council (2003).

Source: International Energy Agency (IEA) (2004)

The reserve estimates shown in the table indicate that supplies of coal could be maintained from a much more diverse range of countries, including many OECD countries. Hydrogen could be produced from coal like from natural gas and the CO_2 released in the process can be captured and sequestered.

Even though there are coal reserves in many countries, the bulk of it is concentrated just as the oil and natural gas resources. Only 6 countries (USA, Russia, China, India, Australia, and South Africa) control 85% of the global hard coal reserves and production (Gerling, Rempel et al. (2006)). The risk that these countries will develop a coal cartel parallel to OPEC by is, however, not overwhelming.

In the future the estimates of economically exploitable coal resources could be limited by two developments. First, transport costs are a major component in the cost of coal. According to Gerling, Rempel et al. (2006) it made up about half of the cost in 2005. Inclusion of international transport in the international climate policy efforts could make international transport more expensive and thus, e.g., South African coal less interesting to European markets. Similarly, carbon capturing and sequestration could become compulsory for future coal power plants in Europe and it will also add to the cost.

The limiting factor for the use of coal for hydrogen production in Europe is, however, not so much the resource scarcity, but much more the cost and capacity of CO_2 capturing and sequestration.

Summing up, the geographical distribution of the natural gas resources does not suggest market structure that is much different from the oil market. Neither will it differ significantly with respect to the countries that are able to pursue their goals through this market power. Coal does, however, - notwithstanding its environmental and energy efficiency drawbacks – offer an energy source with good prospects for supply security.

Global Scarcity

There is long standing debate between resource pessimists foreseeing exhaustion of non-renewable fossil energy resources and resource optimists claiming that proven oil reserves have continued to rise despite increasing oil extraction. Irrespective of who is right, however, the economic concerns rest on the geological fact that even if there is enough oil for 50 or 100 years there will be a point beyond which supply cannot *grow* at the same rate as demand. This is the peak of oil production.

The *estimates* of ultimately recoverable oil resources in the world has increased during the recent decades, but the *actual* ultimately recoverable oil resources is by definition constant and the remaining oil resources are shrinking. Because of this finiteness the supply of conventional oil will peak. The existing conventional oil fields in the OECD countries have already peaked and supply from other non-OPEC sources are expected to peak within the coming two decades. However, with sufficient investments it should be possible to get more out of the existing reserves, discover and develop new reserves and add non-conventional oil.

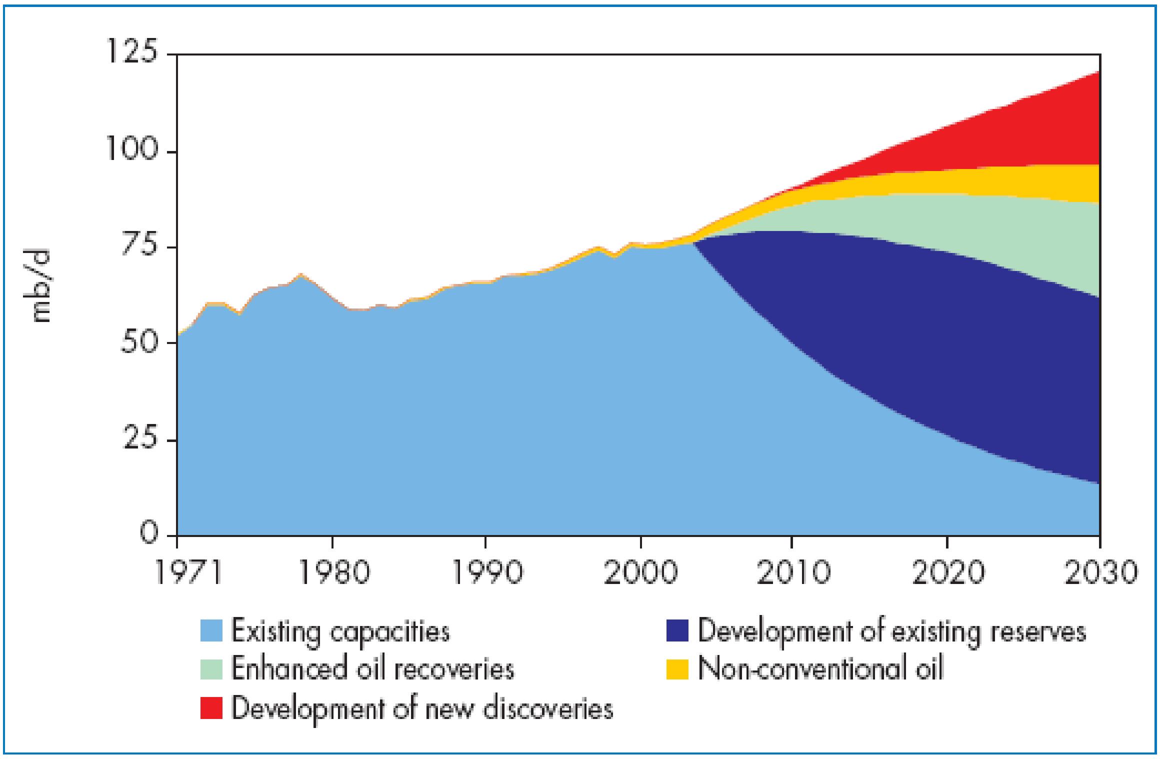

Figure 5. World Oil Production by Source

Source: International Energy Agency (IEA) (2004)

The International Energy Agency (IEA) (2004) expects the world production of oil (all sources and non-conventional oil included) to peak around 2030. The peak may occur up to 5 years later, but it can also occur as early as around 2020.

The recent difficulties of oil supply to the world market in keeping pace with the surge in oil demand suggests that the investments required to bring the remaining oil on stream may be larger than previously assumed.

European energy policies have in many countries supported the substitution of oil and coal in heating and electric power generation by natural gas. However, even though the resources are enough for sustaining the consumption in 2004 for 66 years (International Energy Agency (IEA) (2004)) the natural gas production will peak at some time - just a little later than oil.

It follows directly from these geological realities that replacing oil as the primary energy basis for transport fuel by natural gas could delay or circumvent the oil peak in a short period of time, but only to hasten the natural gas peak.

The International Energy Agency (IEA) (2006) begins the World Energy Outlook 2006 with the following statement: *"The energy future which we are creating is unsustainable. If we continue as before, the energy supply to meet the needs of the world economy over the next twenty-five years is too vulnerable to failure arising from under-investment, environmental catastrophe or sudden supply interruption."*

One of the root causes of this unsustainability is that energy is based on non-renewable resources and, in particular, fossil fuel combustion. For Europe, the finiteness of these resources is important than for other parts of the world. Europe consumed in 2005 18.5% of the non-renewable energy resources that were consumed that year, but only 7.9% of the global production was produced in Europe. Europe relies on foreign supplies of non-renewable primary energy to a degree that is not paralleled by any other region in the World.

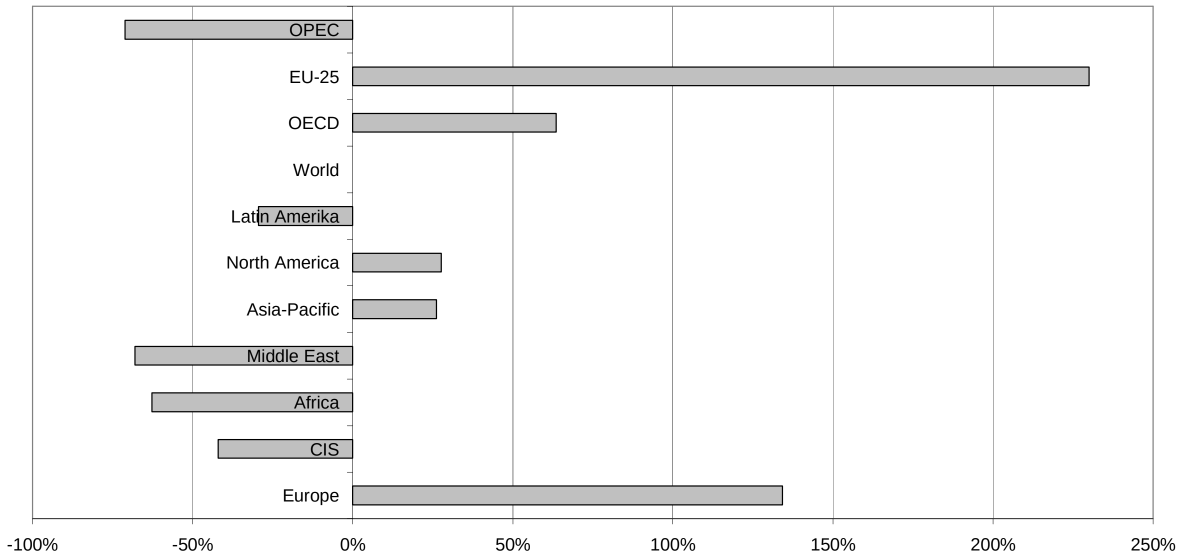

Figure 6. Ratio of Foreign to Domestically Produced Non-Renewable Energy in Main Regions of the World in 2005.

Source: Author's calculation based on data from Gerling, Rempel et al. (2006).

In the future, this dependency on dwindling non-renewable resources from other regions of the world because the Europe's share of the remaining non-renewable energy resources is less than half its share of non-renewable primary energy production in 2005.

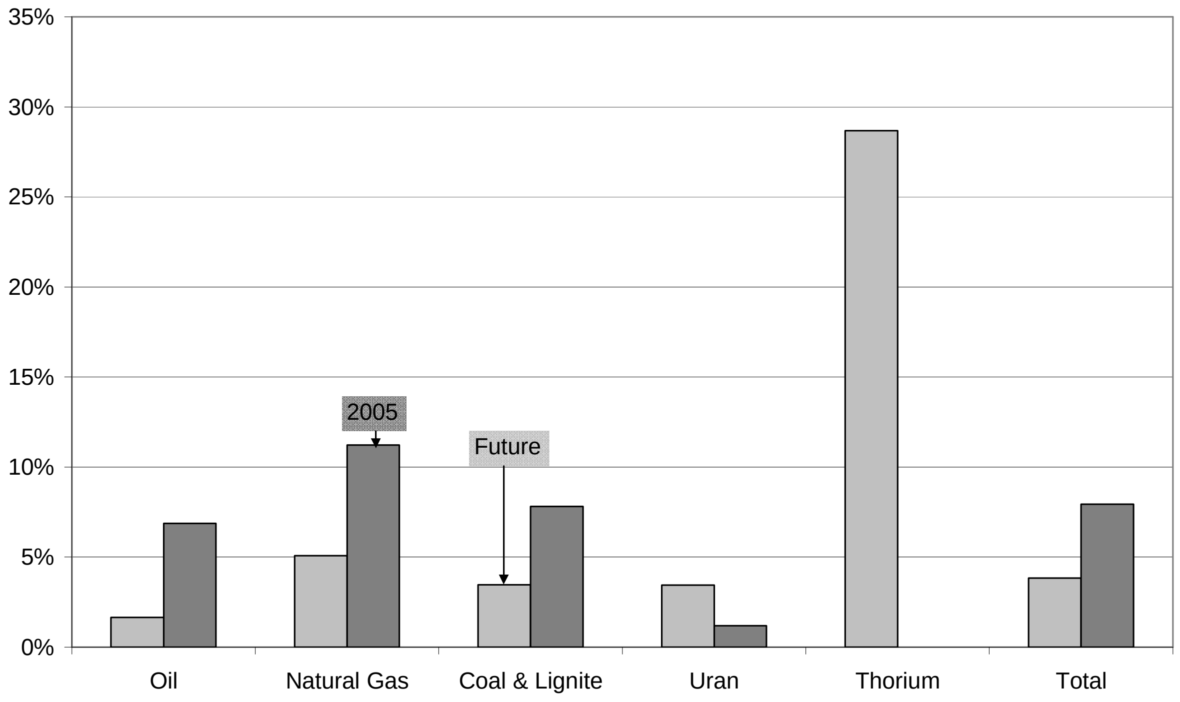

Figure 7. European Share of Global Non-Renewable Primary Energy Production.

Future production of non-renewable primary energy is calculated as the sum of reserves and resources at the end of 2005. Reserves are the proven deposits that are economically exploitable with known technologies. Resources are potential reserves taking into account new discoveries, progress in extraction technology, and higher energy prices. Within the carbon dioxide absorption capacity of the global carbon cycle it is, however, not feasible to combust all of the remaining resources without carbon capturing and sequestration. Adding the cost of carbon capturing and sequestration to the cost of producing fossil energy will probably reduce the estimates of economically exploitable fossil fuel resources.

Source: Author's calculation based on data from Gerling, Rempel et al. (2006).

The figure shows that continued reliance on fossil fuels will make Europe more dependent on resources outside of Europe that are becoming more and more scarce. These realities are in contrast to the societal priorities in Europe of a higher share of domestically controlled energy supply and a lower reliance on dwindling non-renewable energy sources.

Thorium represents a remarkable exception, which is expected to a very important feedstock for fourth generation nuclear power, but the technology is not yet developed.

The conclusion to this is that the long term supply security problem – the geological scarcity – is more serious for Europe than for other regions in the world. Except for thorium, the exhaustible energy sources in Europe will be exhausted within a relatively short time horizon. The energy resources that Europe commands in the future are simply not the non-renewable ones.

Non-Fossil Energy based Hydrogen

Non-fossil Resources and Prices

The non-fossil resources available for hydrogen production includes renewable electricity sources that can be transformed to hydrogen via electrolysis (possibly by high temperature) and biomass from which hydrogen can be extracted by gasification or fermentation. The prices may vary in parallel with the fossil fuel prices for the same reasons: They are substitutes to fossil fuels and their production and transport can be energy consuming. As hydrogen enables a more widespread use of this energy in transport activities they become closer substitutes to oil.

Renewable Resources in Europe

The alternatives to non-renewable energy include renewables like hydro, wind, wave, geothermal, solar, waste (all grid dependent) and biofuels. Europe is well endowed with these resources, but their energy potential cannot be accounted for in exactly the same way as the non-renewable resources. Moreover, the usefulness of their energy is much higher since the grid-dependent energy sources don't involve the conversion loss that is characteristic of fossil fuel combustion.

Renewable energy resources are classified in theoretical (or scientific), technical, and realisable potential. The scientific potential can be estimated with a high degree of accuracy based on meteorological and other physical observations. The technical potential depends to a higher degree on assessments of the efficiency of available technologies. The realisable potential is, however, difficult to estimate for a number of reasons. One of them is that renewable energy technologies are more area intensive than exploitation of most non-renewables is. The value of alternative uses of area plays a decisive role for how much renewable energy is available. However, similar area constraints are limiting realistic non-renewable energy production depending on the location of carbon sequestration and nuclear power plant and waste deposits.

The area requirement of renewable resources is accentuated by the property that most of them (wind, wave, solar, geothermal) are power and heat sources requiring proximity to populated areas or a transmission system which enables transport over long distances without loss of energy.

Thus, it is difficult to calculate the exact amount of renewable energy that could be harvested in Europe. Acceptance of energy technologies and of actual location of plants and infrastructure, future investments in the European transmission grid and the progress rate in performance and cost of energy technologies are decisive factors, which are hard to quantify or predict. However, the present intensity of use of renewables in electricity supply could be an indicator of at least how well Europe is equipped with these factors so far.

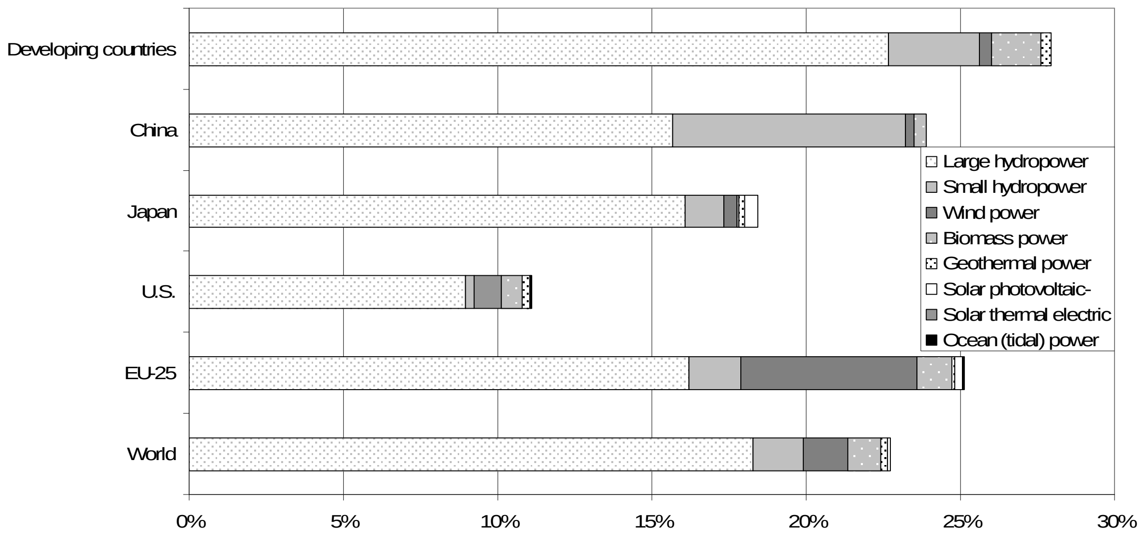

Figure 8. Contribution of Renewable Energy Sources to Total Electricity Supply
Source: Authors's calculations based on Worldwatch Institute (2007).

The figure shows that renewable energy contributes considerably more to the electricity supply in Europe than in Japan and USA. However, this doesn't mean that the unexploited renewable energy potential is particularly large in Europe. In fact, according to International Energy Agency (IEA) (2006) the hydropower generation capacity in Europe can still be expanded by about 75%, whereas other regions in the world have much larger potentials.

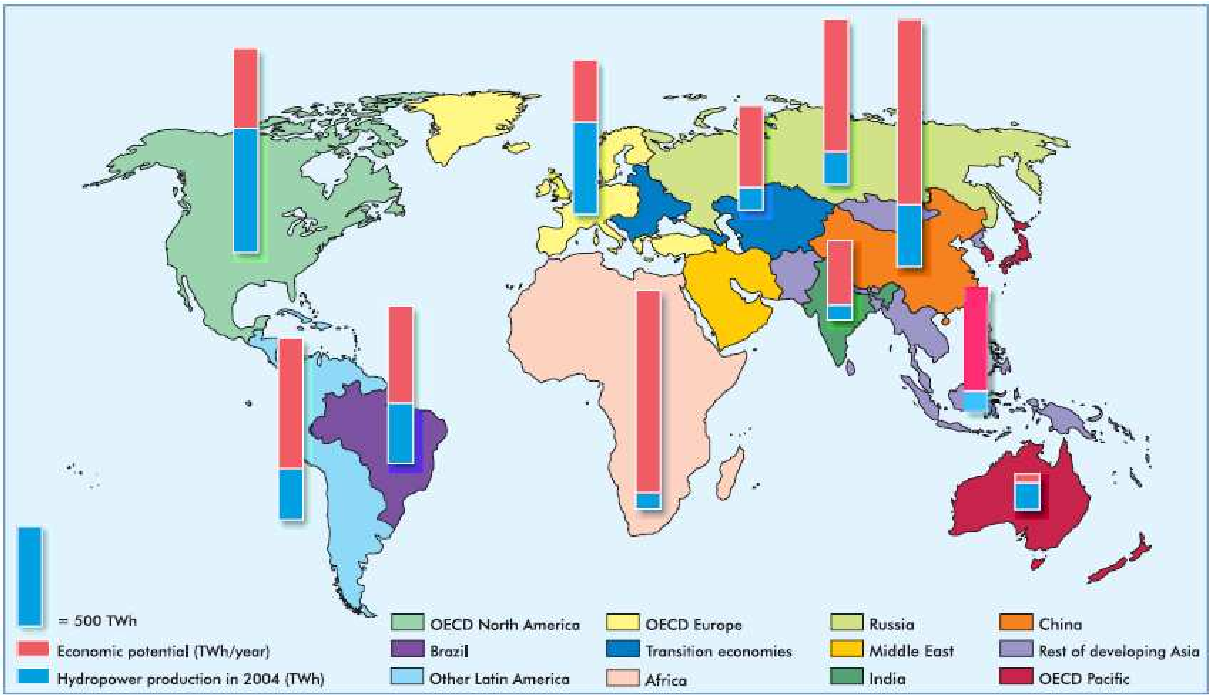

Figure 9. World Hydropower Potential.
Source: International Energy Agency (IEA) (2006).

According to the resource assessment shown at the figure, the largest potentials for development of additional hydropower capacity are in the developing countries.

Non-hydropower renewables are, however, new and rapidly growing sources of electricity. The countries that are leading in taking these new technologies into use are all European (except New Zealand) as shown on figure 7.

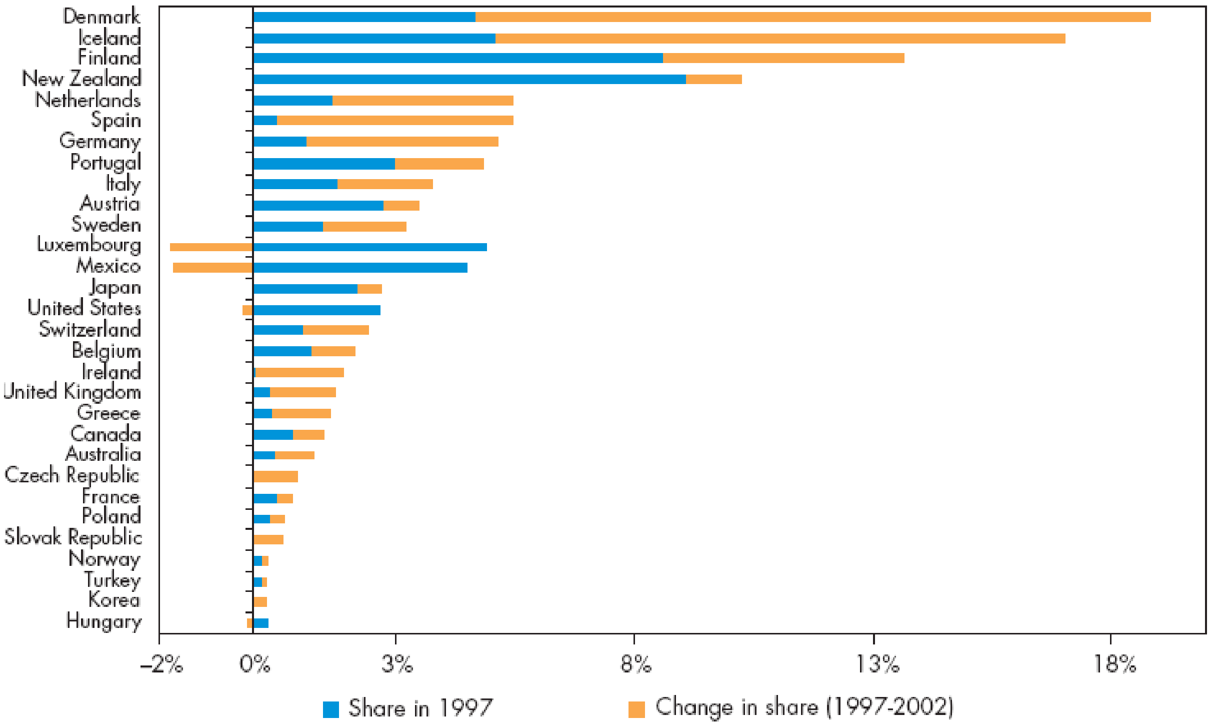

Figure 10. Share of Non-Hydro Renewables in Electricity Generation in OECD Countries, 1997 and 2002.

Source: International Energy Agency (IEA) (2004).

The figure also shows that the share of non-hydro renewables in electricity generation can change dramatically in just 5 years. This is reassuring for the binding target of 20% renewable energy adopted by the European Council and the even more ambitious targets debated in individual member states. The most ambitious vision is the postcarbon society, that is, a society where fossil fuel combustion is history at least without carbon capturing and sequestration. Together with the potential for nuclear energy and fossil energy with carbon capturing and sequestration there are sufficient European energy resources to fully supply the European energy needs if so desired.

Most of these resources are, however, sources of electric power. Electric power has limited opportunity for application in a transport sector, which is technologically locked in to combustion of oil-based transport fuels. The most important mission of hydrogen and fuel cell technology is that it offers an opportunity to use electricity (and second generation biofuels) for automotive purposes. In this sense, it is a prerequisite for satisfying the European energy demand not only related to stationary process, heating, lighting, but also for transport on European sources renewable, nuclear, and fossil-CCS energy. Hydrogen and fuel cells offers an opportunity to base European transport on European energy sources, but it should be noted that the actual shift from oil to European sources is a process that probably runs over several decades.

Thus, the potential for renewable energy depends very much on socioeconomic factors such as the willingness to use land areas for energy purpose, the investment in transmission infrastructure to exploit remote (e.g., at sea) sources for renewable electricity, and the capacity of the power system to absorb power supply from intermittent sources.

Hydrogen offers the opportunity to store intermittent power and therefore represents a direct solution to the latter problem. In this sense hydrogen technology can increase the capacity of the European power sector to make use of domestic renewable sources of electricity and thereby strengthen supply security.

The potential for the second non-fossil source of hydrogen feedstock, nuclear power, shares similar conditions. The binding constraint is the willingness to abandon land areas that can be used for location of power plants and final deposition. Expansion of the power generation and final deposition capacity will be of least cost at locations that already are abandoned for nuclear power purposes.

Hydrogen technology does not change this, but it can make use of the economies in a constant load by producing hydrogen with off-peak electricity.

The third non-fossil non-fossil source of hydrogen feedstock is biomass. Biomass is used to generate hydrogen directly through gasification or fermentation rather than indirectly through combustion, power generation, and electrolysis. Biomass is the most dispersed source of energy and thus

The conclusion is that hydrogen technology offers a way to get more useful energy out of the power generation capacity even if it is base-load or intermittent. Thereby, it enables large market shares for European and in this sense more reliable energy sources.

Hydrogen and security of energy supply

Hydrogen and fuel cell technology will enable Europe to diversify the primary energy basis of transport fuels to a variety of alternative feedstock. In the following table we summarize the results

Table 2. Supply security impacts of substituting oil by alternative feedstock as primary energy basis for transport fuels.

Feedstock	Price	Market power and geopolicy	Global scarcity
Natural gas	0	0	0
Coal	+	++	+
Renewable electricity	+++	+++	+++
Biomass	++	+++	+
Uranium	+++	+	+
Thorium	+++	++	++

To sum up from the preceding sections it is not easy to find empirical support for the idea that the supply of hydrogen based on natural gas will be more secure than the supply of petrol and diesel based on oil.

In general, natural gas and to some extent coal prices change very closely in parallel with oil prices. Given the close substitution with oil, it is unlikely that the price of natural gas becomes independent of the oil price. When the geographical distribution of the remaining natural gas resources is taken into account, the prospects of developing competitive spot markets with prices independent of the oil price are not good.

Globally, the future supply of natural gas is controlled by the same countries controlling the future supply of oil and a "Gas-OPEC" is a realistic possibility.

Coal resources are concentrated too, but the risk of collusion between the governments involved is rather small. Coal resources are non-renewable and in this respect global scarcity is still an issue although there is enough of it. In particular, Europe will be increasingly dependent on non-renewable resources from other parts of the world.

In contrast, hydrogen based on non-fossil electricity or directly extracted from biomass would represent a rather secure source of energy supply. There is little reason to expect use of market power and political instability to give rise to supply disruptions in these markets.

Renewables like hydro, wind, wave, and solar and nuclear like thorium reactors have the potential to eventually be the dominant supply technologies with prices independent of oil.

Biomass is renewable, but limited in comparison with the energy consumption in Europe as well as globally. The contribution of biofuels to global transport energy demand will hardly exceed 25%. In this sense it is globally scarce although it is renewable.

Uranium is not plentiful in Europe, but Europe is well endowed with thorium, which often is advocated as promising candidate for fourth generation nuclear power technology.

These conclusions are in line with a recent analysis of energy supply security by International Energy Agency (IEA) (2007a). This analysis finds that for a sample of European countries it would benefit energy supply security to replace fossil by non-fossil fuels in power generation, but not to replace coal by natural gas. However, replacing petrol and diesel by biofuels would give lower risk from disruption of oil supplies but higher risk from disruption of natural gas supplies that is an important input in biofuel production.

In addition to the supply security of feedstock, it should be noted that two properties of hydrogen must be expected to improve the security of energy supply associated with renewable energy in Europe. First, hydrogen is highly "convertible" from any energy form and to electricity. Concurrently with reduction of the loss of energy in these conversions hydrogen will facilitate a much more diverse structure of primary energy sources. Second, hydrogen can store the energy produced by intermittent sources and by base-load plants in off-peak periods.

Oil and gas dependency

Oil and gas dependency ratio

Disruption of oil supplies are of course not equally important to all countries. Some countries rely more on oil than others. To analyse the difference in oil dependency – and the challenge of becoming oil independent – we use a net export measure as described below.

As shown above, oil and natural gas are very close substitutes and the oil and gas dependency is more informative than the oil dependency alone. Thus instead of net oil imports, the net imports of oil *and* natural gas is the interesting issue.

The analysis of natural gas and crude oil price shows that in the past the natural gas price has been remarkabley stable relative to the oil price. Thus the two primary energy commodities can be combined to one aggregate oil and natural gas commodity.

The degree of oil and gas dependency can be measured as the amount of oil and gas the economy imports (net of exports) compared to GDP , the aggregate output (or income originating from this output) of the economy. Oil price increases (and subsequently natural gas price increases) raise the import bill, but the export revenue as well. How important the net bill of an oil and gas price increase is to the economy, therefore depends on the ratio of net import of oil and gas to GDP.

This oil and gas dependency ratio can be derived from trade statistics and national accounts, but also from production and consumption figures. The math behind this takes departure in the identity of supply and use of a given commodity (assuming no stock changes).

$$Y + M = D + X \Leftrightarrow M - X = D - Y \Leftrightarrow (M - X)/GDP = (D - Y)/GDP,$$

where

Y: Primary production of oil and natural gas

M: Imports of oil and natural gas

D: Gross inland consumption of oil and natural gas

X: Export of oil and natural gas

All variables are assumed to be in quantities of a homogeneous quality.

Equation (1) states that if supply equals use (or demand), then net import of oil and natural gas is equivalent to the difference between domestic consumption and domestic production of oil and gas. The ratio of this difference to GDP is as good an indicator for oil dependency as the ratio of net import to GDP is.

A low rate of production or a high rate of consumption (or both) to GDP makes the economy more vulnerable to an increasing oil price as described above. The figures below show how these two components affect the vulnerability of the European economies.

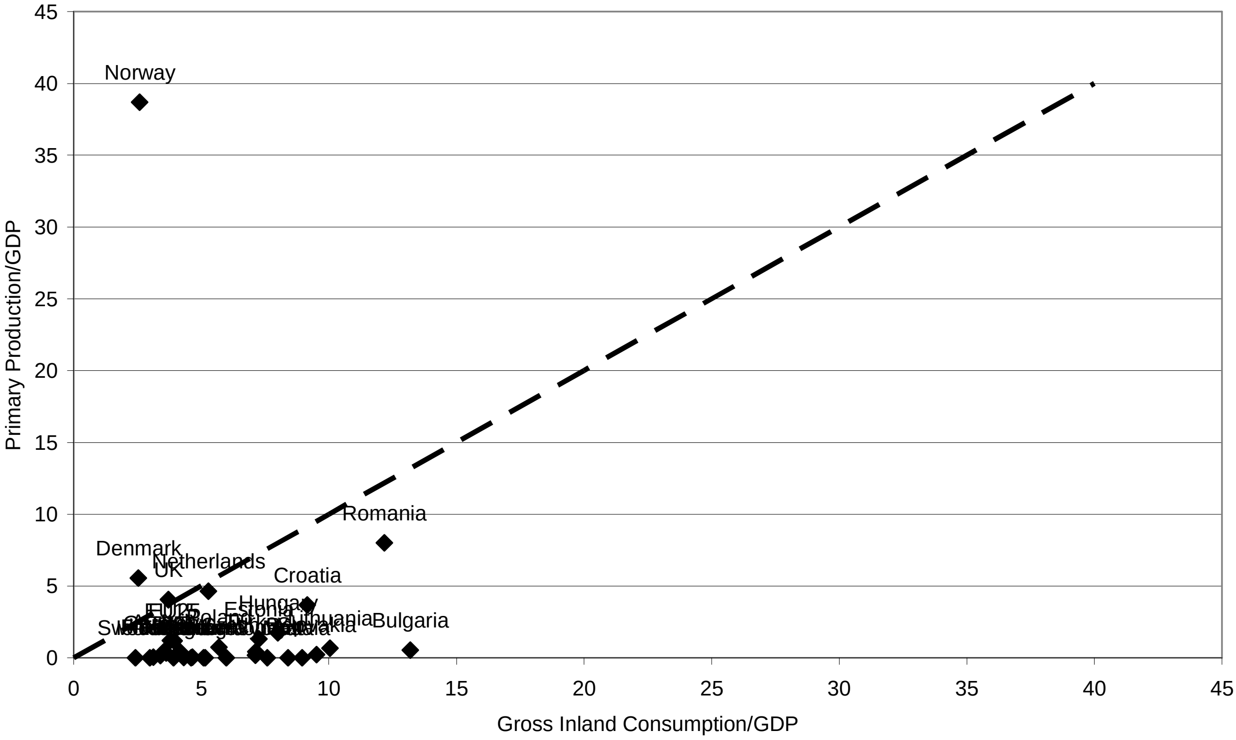

Figure 11. Primary Production and Gross Inland Consumption of Oil and Natural Gas as Ratios to GDP for European Economies (2004, MJ/€).

Source: Eurostat Online Database, National Accounts and Energy Statistics.

The production and consumption of and natural gas are measured in net calorific content whereas GDP is measured in € (2005 prices). The lower price per energy content of natural gas (cf. above) is reflected by adding 85% of the natural gas energy to the oil energy. The dotted diagonal line is the balance between the production and consumption rate that would leave an economy unaffected as to the primary terms of trade effect of oil price increases. Economies to the right of the line har negative terms of trade effects from oil price increases whereas economies to the right of the line have positive effects. The further from the line, the stronger effects.

The figure shows that in particular Norway, but to some degree Denmark as well in 2004 benefitted from increasing oil prices whereas UK, the Netherlands, and Romania are close to neutrality. Bulgaria seems to be the most vulnerable of the European economies.

The following figure offers a closer look at the economies with production and consumption rates below 10 MJ per €.

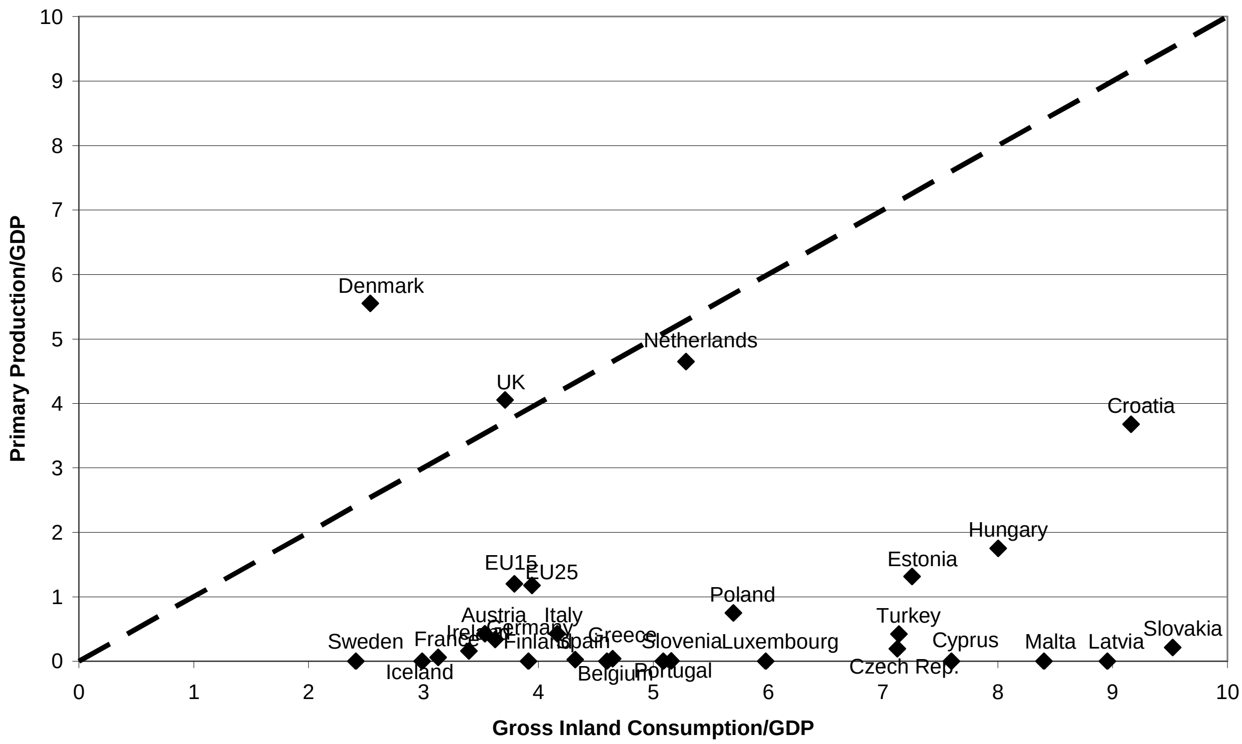

Figure 12. Primary Production and Gross Inland Consumption of Oil and Natural Gas as Ratios to GDP for European Economies with Rates below 10 MJ per € (2004, MJ/€).

Source: Eurostat Online Database, National Accounts and Energy Statistics.

The EU economies are with a few exceptions - Denmark, UK, and the Netherlands - very vulnerable to future oil price increases. As the oil and natural gas fields are depleted in the coming decades, these countries will be as vulnerable as the other EU15 countries with a energy consumption to GDP ratio of 2.5-5 GJ/€. Most of the vulnerability of Europe is, however, in the EU10 economies. The figures suggest that if they apply the same technological and institutional solutions as in EU15, they can double or triple their production without increasing their energy consumption.

It is possible that some of the EU10 countries will find it attractive to produce non-fossil energy or hydrogen for export to EU15. However, the primary strategy for closing the vulnerability gap will probably be to implement the technological and institutional solutions that have produced a lower dependency rate in the EU15 countries.

Any strategy aiming at an oil price resilient economy must include measures that expand primary production of oil and gas or equivalent fuels or reduce oil and natural gas consumption or both. To attain oil price neutrality would at the present rate of oil and gas production would require a reduction of the consumption rate by more than 70%. However, the oil production in Europe is already declining and the natural gas production will follow suit.

The countries facing the most adverse macroeconomic effects of future oil price increases are those with less economic strength.

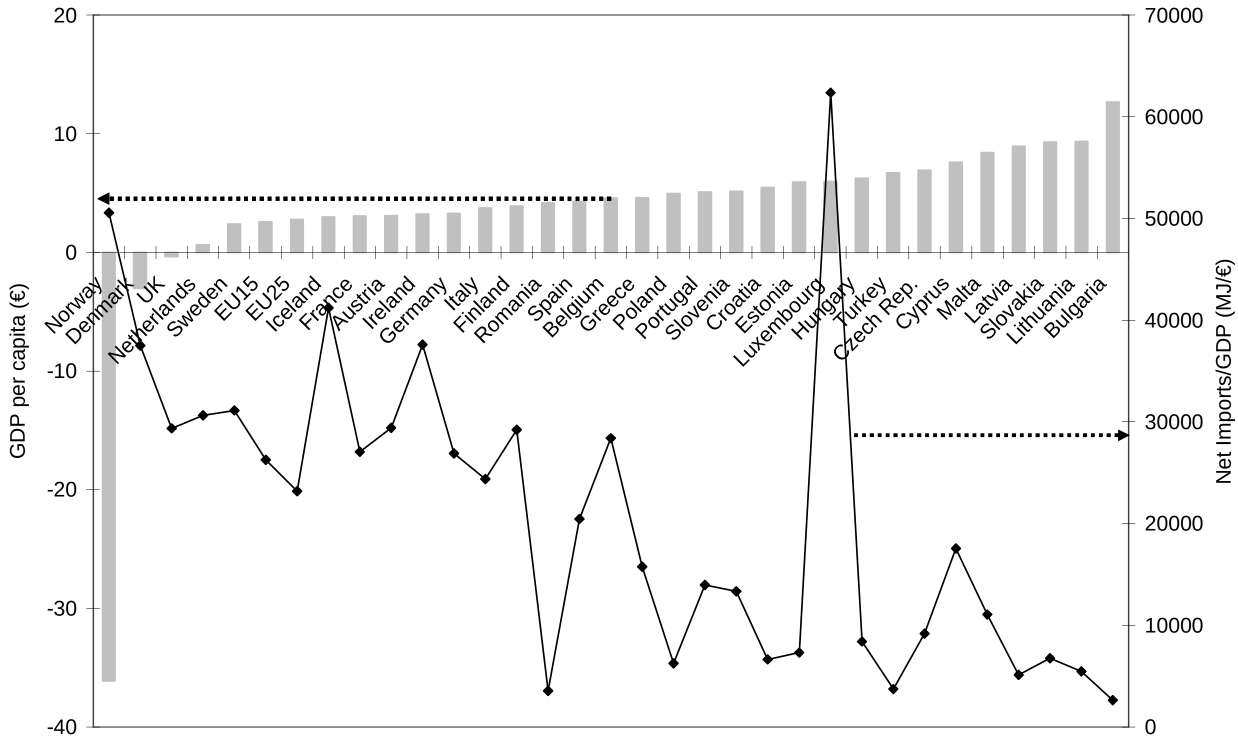

Figure 13. Oil and Natural Gas Dependency and Per Capita Income in Europe (2004).

Source: Eurostat Online Database, National Accounts and Energy Statistics.

The figure shows most European countries arranged according to their oil and natural gas dependency and their per capita income in 2004 (in 2005 prices). With a few exceptions (Luxembourg, Belgium, and Spain), the most vulnerable economies are those with income levels below €20,000 per capita, whereas those with incomes above this level are more resilient.

Conclusions

The conclusion is that the macroeconomic effects of substituting petrol and diesel by hydrogen are not so much related to the hydrogen itself. It is only an energy carrier and the effects of using one energy carrier for another are not important from a macroeconomic point of view. Likewise the effects of using one power-train technology in the vehicles rather than another.

The macroeconomic effects are related to whether the hydrogen is produced from domestic or foreign energy sources. In the long term natural gas as well as oil will be exclusively imported to Europe whereas the domestic resources will include renewable energy sources as well as nuclear waste and carbon deposition capacities.

The development of the domestic resources will make the European economies less dependent on oil price increases and could contribute to the full realisation of the employment growth potential.

If domestic production of hydrogen based on domestic resources should contribute to less vulnerable

Natural gas based hydrogen can like imported bio-fuels be a necessary stepping stone to the realisation of the domestic energy sources.

This raises the questions for future research of dynamics and sequencing of phasing in and phasing out of the particular primary energy/fuel transformations.

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